8th Microoptics Conference (MOC '01), Osaka, Japan, October 24-26, 2001

M4 (Invited)

Advances in GaInNAs Edge Emitting Laserdiodes

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Abstract

GaInAsN/AlGaAs laser structures have been investigated in the telecommunication wavelength range from 1.3 µm to 1.5 µm. By molecular beam epitaxy with an RF – nitrogen source we have grown layers with room temperature photoluminescence linewidths of 30 meV at 1.3 µm. Based on the layers separate confinement laser structures are obtained which yield threshold current densities of 780A/cm^2 in broad area devices. Ridge waveguide lasers show threshold currents of 21mA and external efficiencies of 0.5 W/A. Using metal gratings along both sides of the ridge loss coupled distributed feedback lasers have been obtained with side mode suppression ratios above 40dB. When the N – fraction is increased to about 5% the emission wavelength of the lasers is shifted to 1.5 µm. Due to increasing defect formation the laser threshold increases significantly when the 1.5 µm range is reached.

I. Introduction

After the first studies by Kondow et al.[1)-2)] a few years ago the quaternary alloy GaInAsN has become the center of intense studies focusing on the realization of long wavelength telecommunication lasers based on GaAs. Currently this wavelength range is dominated by the GaInAsP/InP material system. Due to some drawbacks of the InP – based system, e.g. a rather strong dependence of the laser threshold current on temperature or the small difference in refractive index available for lattice-matched materials (which complicates the realization of vertical cavity surface emitting lasers) GaAs based telecom lasers with superior properties have a high potential.

During the last years GaInNAs edge emitting lasers as well as vertical cavity surface emitting lasers (VCSELs) with application grade properties have been realized by different groups in the 1.3 µm wavelength range.[3-8)] Both molecular beam epitaxy (MBE) [3)-4)] and metal organic chemical vapor deposition (MOCVD) [5)-6)] have been used. The high conduction band offset in the GaInAsN/GaAs system results in excellent high temperature device performance at 1.3µm [7)-8)]. In addition, the possibility to monolithically combine GaInAsN active regions with AlGaAs based distributed Bragg Reflectors (DBRs) makes this material system highly attractive for long wavelength vertical-cavity surface emitting lasers (VCSELs) [9)-10)].

We have grown GaInAsN/GaAs single and multiple quantum well laser structures by plasma assisted MBE Laser structures with p-type doping by Carbon exhibit very good device properties. Ridge waveguide laser diodes at 1.3µm under continuous wave (cw) operation at room temperature (RT) show thresholds of 21mA with efficiencies exceeding 0.5W/A. The lasers can be operated pulsed up to 150°C and show a T_o of 158K up to 110°C. By increasing the N – content lasers emitting at up to 1.5µm have been realized.

II. Epitaxial growth, layer characterization and device fabrication

The laser layers are grown by a vertical solid source MBE made by Eiko Engineering. Separate confinement heterostructure lasers were grown on (001) oriented n-GaAs substrate. A radio frequency (RF) plasma source supplies active nitrogen from high purity N_2 gas. The handling of the nitrogen may influence the quality of the active layers as well as of the waveguide and cladding layers. In particular, the fairly high pressure required for a reliable RF – plasma source operation cannot be suppressed sufficiently by a conventional MBE shutter while growing e.g. the waveguide section of the lasers. When using such a shutter in conjunction with an ECR nitrogen source we have noted for example, that the waveguide includes about 0.25 % of nitrogen, i.e. binary GaAs waveguide layers cannot be realized. We have therefore separated the RF – nitrogen source by a UHV gate valve from the growth chamber. This allows the use of these (N-free) GaAs barrier layers and results in an excellent heterointerface quality between the N-containing and N-free layers.

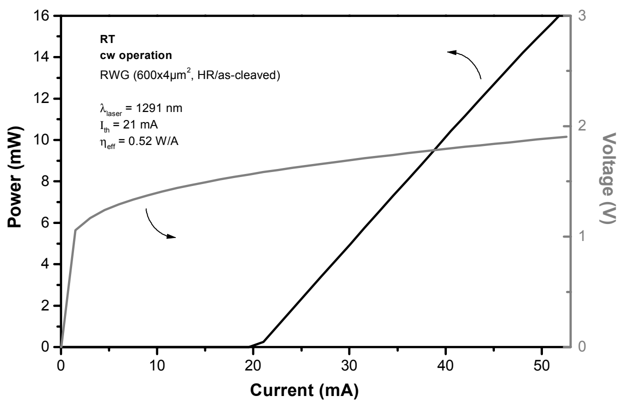

Fig. 1 cw P-I and U-I characteristics of a 1.3 µm GaInAsN RWG LD (facets: HR/C) at room temperature.

The active region of the lasers consists typically of compressively strained GaInAsN QWs symmetrically embedded in a 320nm thick undoped GaAs waveguide. The N-content in the QW is around 1.5 to 2% for 1.3 µm emission. 1.6µm $Al_{0.4}Ga_{0.6}As$ doped with Silicon and Carbon is used as n- and p-type cladding layer. A 140 nm p+ doped GaAs cap serves as a contact layer.

From these layers as well as from layers for 1.4 and 1.5 µm emission ridge waveguide (RWG) lasers (with nitrogen content up to 5%) have been defined by standard photolithography and transferred into the laser layers by dry etching using an electron cyclotron resonance assisted reactive ion etch process (ECR-RIE) with a Cl_2/Ar mixture. For insulation and planarization probimid is spin coated and subsequently etched by an O_2/Ar-plasma. Ti/Pt/Au and AuGe/Au contacts are evaporated and annealed. The lasers are finally cleaved into bars with different lengths. A high reflectivity (HR) coating is applied to one facet of the RWG lasers. The output facet is as-cleaved (C). The unmounted devices are then tested on a temperature controlled heat sink.

III. Device characterization

Broad area (BA) double quantum well lasers for 1.3µm emission (1000 µm x 100 µm, as-cleaved) show threshold current densities of 780 A/cm^2 . The threshold current density (interpolated for infinite cavity length from broad area devices) of the SQW laser structure used was determined to 490A/cm². At higher N – content we observe a clear increase of the laser threshold.

Figure 1 shows the light output-current (P-I) and voltage-current (U-I) characteristics of a RWG laser (600x4µm^2) under cw operation at room-temperature. Lasing operation starts at a threshold current of 21mA with a slope efficiency of 0.52 W/A.

By defining metal gratings on both sides of the RWG distributed feedback (DFB) lasers based on a complex coupling have been realized.[11)] The Cr stripes provide a strong variation of the real and imaginary part of the refractive index. The resulting complex coupling provides a high single mode yield together with good sidemode suppression ratios (SMSR). Most importantly this technique allows to realize high quality DFB – Lasers without the need to overgrow. This is especially interesting in Al – containing layers as used here, as these layers a likely to be degraded by oxidation during a growth interruption. Fig. 2 shows typical output spectra for two devices with different grating periodicities. SMSRs of around 45 dB are reached.

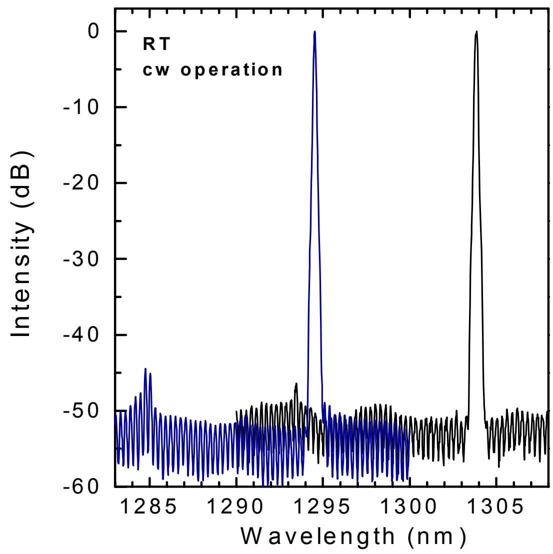

Fig. 2 Single mode laser spectra of two GaInNAs DFB lasers in the 1.3 µm range. The threshold currents of the devices are around 30 mA.

By increasing the N – content to about 5% we have been able to shift the laser wavelength up to 1.5 µm. The increasing N – content, however, results in a sharp increase of the threshold. In order to minimize Joule heating of the devices we have used RWG structures under pulsed excitation for this part of the studies. The RT threshold of the devices occurs at about 550 mA. Fig. 3 shows the output spectrum of a 1.5 µm GaInNAs RWG laser. The emission maximum occurs at about 1.51 µm. The devices operate in pulsed mode up to temperatures of 80°C.

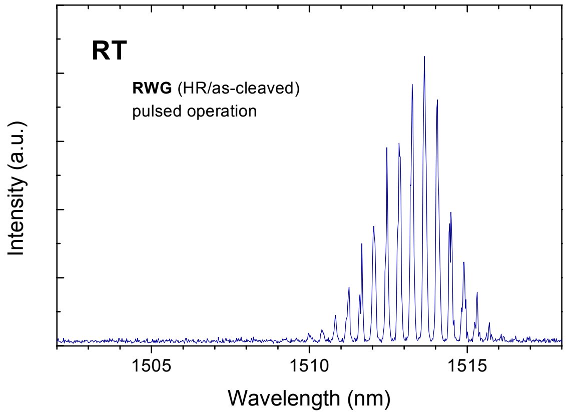

Fig. 3 RWG spectrum of a 1.5 µm GaInNAs laser.

IV. Conclusion

We have developed high quality GaInAsN/GaAs laser layers by solid source MBE using an RF plasma source for nitrogen generation and Carbon for p –type doping.

Here and in the literature we have reported data on BA and RWG lasers at 1.3 µm. By using lateral metal gratings we have realized DFB – lasers with very good properties. The lateral grating technique is especially powerful for Al – containing systems avoiding difficulties in the commonly used overgrowth of etched grating patterns. By increasing the N – content from about 2% to about 5 % the emission wavelengths of the GaInNAs – lasers can be shifted from the 1.3 µm range to the 1.5 µm range. Overall our results indicate the large potential of the GaInNAs – material system for LDs in the entire telecommunication range.

Acknowledgement

The financial support by the VOLKSWAGEN STIFTUNG and the State of Bavaria is gratefully acknowledged. The work at nanoplus was partly funded by the European IST research project GIFT.

The authors also wish to thank A. Wolf, S. Kuhn and E. Rowlett for expert technical assistance.

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